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DEVELOPMENT OF A HOG MANURE PIPELINE CONTROL SYSTEM

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Final Report

Development of a Hog Manure Pipeline Control System

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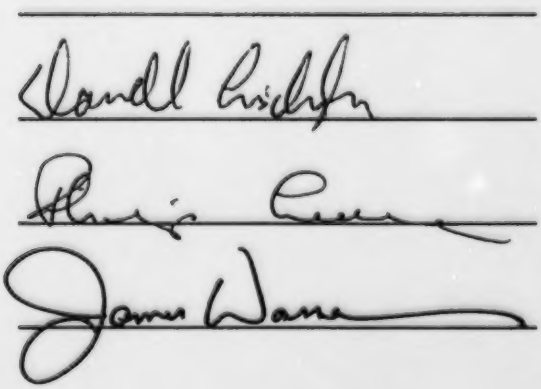

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1. Introduction

Pipeline manure handling systems are becoming popular for moving large amounts of manure from the manure storage to the field injector. They have the advantage of being able to handle large volumes of manure in a continuous flow manner with no municipal road damage. However, some units are largely a system assembled from irrigation components, and therefore there are some components missing that would enhance the system operation. One of these components is a system to turn the manure flow on and off from the injector tractor. This would be a useful feature as the cultivator is lifted out of the ground when turning around at the ends of the field, and it would prevent manure from being spilled on the soil surface. The system could also be used to shut off the manure flow in the case of a line break or other malfunction.

This project was carried out to try to solve these problems by developing and testing a prototype on/off device for a pipeline manure handling system.

2. Objectives

The objectives of this project were to:

1) Develop a system to turn the manure flow on and off in a pipeline manure system using remote control.
2) Test the system during a typical manure pumping season.

3. Summary and Conclusions

A system to remotely control the starting and stopping of manure flow in a manure pipeline injection system was developed. A preliminary design was done to determine system parameters and various control components were selected. The system was assembled and initial testing was carried out. A control strategy was developed that would provide satisfactory operation, adequate system protection, and flexibility to allow adjustment of the system operation during testing.

Initial tests were done with no manure flow and some programming changes were completed. After the initial tests, full-scale tests were done and after some adjustment, the system operated well. Some problems occurred during operation but were addressed and the changes were lab tested.

4. General Description

The pipeline manure handling system used in this project was largely assembled from components from the irrigation industry. The main pump was a centrifugal pump driven by a stationary diesel engine. The pump inlet was a section of aluminum pipe placed into the Earthen Manure Storage (EMS). The pump outlet was attached to a section of flexible hose with a fitting on the outlet end for connection to standard 6 in. aluminum irrigation pipes. Many of these pipe sections were connected together to transport the manure from the EMS to the field. In the field, two 1,320 ft. sections of flexible drag hose transported the manure to the distributor on a tractor drawn cultivator. A second tractor was needed to periodically reposition a metal "knuckle" that joined the two drag hose sections.

5. Project Scope

The first stages of this project involved preliminary system design. The needed plumbing layout was determined, and a control strategy was determined. Control component characteristics were also determined. Components were then selected, including valves, radio controls, and safety devices to protect the controls and the pipeline. The system was then assembled and preliminary tests done. In the field, the system was tested and refined and finally some auxiliary laboratory testing was also carried out.

Commercialization of the system will be attempted y the electronics contractor with assistance from PAMI by way of PAMI issuing a Research Update and presenting the project to the public at appropriate events.

6. Results and Discussion

6.1 Preliminary Design

Before detailed design was done on the system, some basic operating parameters were determined. It was assumed that simply turning off the manure flow at the cultivator would not work, as it could cause several problems including water hammer (shock waves set up in the liquid caused by rapid fluid acceleration or deceleration), which could overpressure the manure hoses and pipes, and damage the pump from rapid flowrate changes. It was therefore decided to not only turn off the manure flow at the cultivator, but also to simultaneously open a valve at the EMS to recirculate the manure flow back into the EMS. Coordinating the opening and closing of these two valves would be the challenge, as it would be preferable to have the on or off sequence happen as quickly as possible without introducing water hammer or other potentially damaging situations. A small programmable computer with associated electronics was chosen to control the valve opening and closing. Radio modems connected to the electronics both at the EMS and on the tractor cab would provide for communication between both locations.

Other system components had certain requirements placed on them because of the operating environment and operations they would be performing. The valves had to handle manure solids without plugging or manure buildup, as well as being resistant to the corrosive nature of hog manure. All other components had to work in a wet, corrosive environment. The radio control system between the tractor and EMS needed to work reliably with a range of at least two miles in less than ideal terrain and not cause or be subject to electrical interference from normal tractor operation or standard communication radios or cellular phones.

6.2 Component Selection

6.2.1 Valve Selection

Many types of valves were considered for this system. The advantages and disadvantages of all considered are described below.

Three types of valves were immediately discarded because they would almost certainly plug with straws or other solid material. These three types include gate valves, globe valves and butterfly valves. Gate valves are used on some manually operated manure handling systems, but suppliers warned that they may be prone to even partial plugging, and therefore may not work consistently enough to be used in an automatic control system. Pinch valves are simply a section of flexible hose that is pinched to shut

off the flow, but they are not recommended for use as a throttling valve where there is no downstream pressure. In this situation they would be prone to cavitation and a shortened life. Ball valves have no restrictions when completely open, and would probably work well for this situation. However, none that were available from local suppliers were of the correct size and made of the correct materials.

A plug valve consists of a housing that contains a plug that rotates through 90 degrees from open to closed. When open, there is no restriction to flow, and as the valve closes there is a wiping action that helps to dislodge any solids that may have been caught in the mechanism while operating. This type of valve is also quite easy to mechanically actuate, as there is only a 90 degree movement from open to closed, as opposed to other valve types that require several handle turns. This type of actuation lends itself to simple monitoring of valve position. For these reasons, a plug valve was chosen for the recirculating valve at the EMS. A gate valve was already present on the cultivator, so it was used to control the manure flow at the cultivator for this project.

6.2.2 *Actuator Selection*

Calculations were done to determine probable valve opening and closing times that would be quick enough to be practical and would not cause water hammer. Equations developed for the irrigation industry were used for these calculations. These equations consider the compressibility and density of water, pipe diameter, pipe material elasticity and pipe wall thickness to calculate the pressure wave velocity and subsequent instantaneous pressures. The worst case scenario for this project was found to be a valve closing time of 20 seconds. This was thought to be quite long, so the system was designed so the opening and closing of the valves could be changed from 20 seconds to about 2 seconds. This decision affected the actuator selection.

The available methods of valve actuation included electric, compressed air, or hydraulic. Because compressed air was not available at the tractor or the EMS, it was discarded immediately. Electric actuators were available for the plug valve at the EMS, but because this was a large valve, their opening times were several minutes long, which was not acceptable. The speed of these actuators was also not variable, which did not fit this project either. Another option was a factory installed air operated actuator. Because compressed air was not available, we decided to use hydraulic pressure to move the actuator. This would require a pressure reducing valve to reduce

the hydraulic pressure from the standard 2,000 psi available from most tractors to 100 psi. By using hydraulics, the valve speed could easily be changed using a flow control valve. Electric solenoids could also be used to remotely control the valve positioning. All of the above components were assembled and incorporated into the control system. A rotary potentiometer was also installed to indicate valve position.

The gate valve on the cultivator had a hydraulic actuator built into it, but it was not in good working condition. This valve was smaller than the plug valve used at the EMS, so an electric linear actuator that could open or close the valve in a few seconds was available. The actuator was obtained and the valve modified to accept this actuator. This actuator was rated for use in wet environments, and had a built in potentiometer to provide an indication of valve position.

6.2.3 *Electronic Control System Selection*

Electronic control system hardware was readily available for this type of control system problem. Standard components that could survive in a manure pumping environment housed in a suitable enclosure could be used. These components are relatively easy to program, and are also easy to obtain and service. An industry standard 68HC811 microprocessor was used as the CPU and standard opto-isolators and relays were used to convey the information from the CPU to the appropriate electronic components. All of the electronics were housed in a weatherproof enclosure. Weatherproof connectors were used for all external connections.

A similar approach was used in selecting the radio control components. The radio modems chosen are designed to be used in this type of situation where they don't need their own housing, and are used as a communication tool between a stationary and remote device. They were chosen to give adequate communication range while not being so powerful that an operating license was required. The modems were housed in the same enclosure as the other electronic components. A schematic of the control system is shown in **Figure 1**.

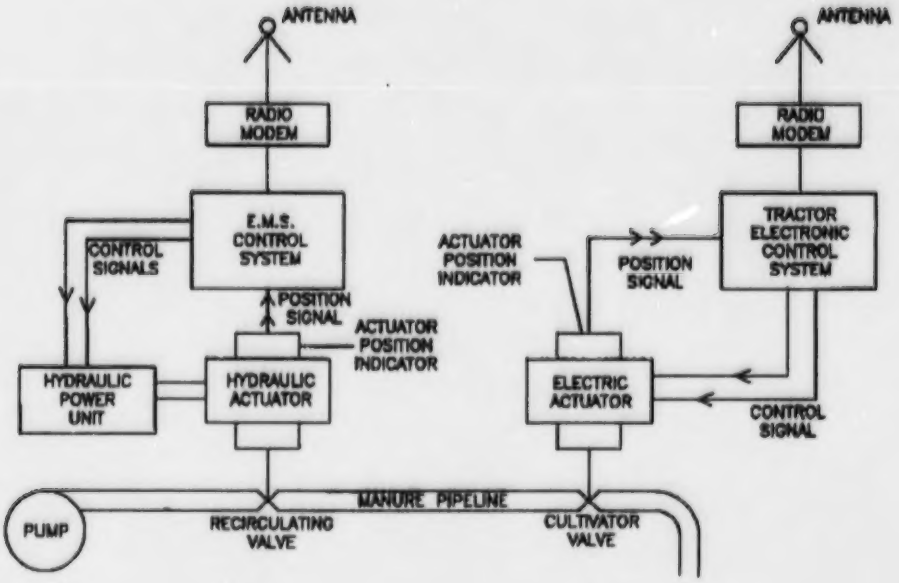

Figure 1. Control System Schematic.

6.2.4 Safety Device Selection

Because water hammer and the potential for excessive operating pressure were a major concern, several steps were taken to minimize possible system damage during initial testing. A check valve was installed immediately downstream of the main manure pump to minimize any pressure waves that may be travelling back toward the pump. The overall test strategy was to initially try long valve actuation times and then to gradually shorten the actuating time while watching for any water hammer problems.

Other measures were taken to reduce the possibility of excessive operating pressure. The overall operating strategy was to open the recirculating valve before closing the cultivator valve when shutting off the manure flow. This would ensure that the flow was never reduced to zero and the pressure would not increase beyond normal operating pressure. For the same reason when turning the manure flow on, the cultivator valve was opened before the recirculating valve was closed. A "safe" mode was designed into the control strategy, so if the controller determined that an error condition existed, the recirculating valve would open. The problem would then have to be corrected before the valve would be closed and manure flow to the cultivator resumed.

6.3 System Assembly

A schematic of the entire assembly at the EMS is shown in **Figure 2**.

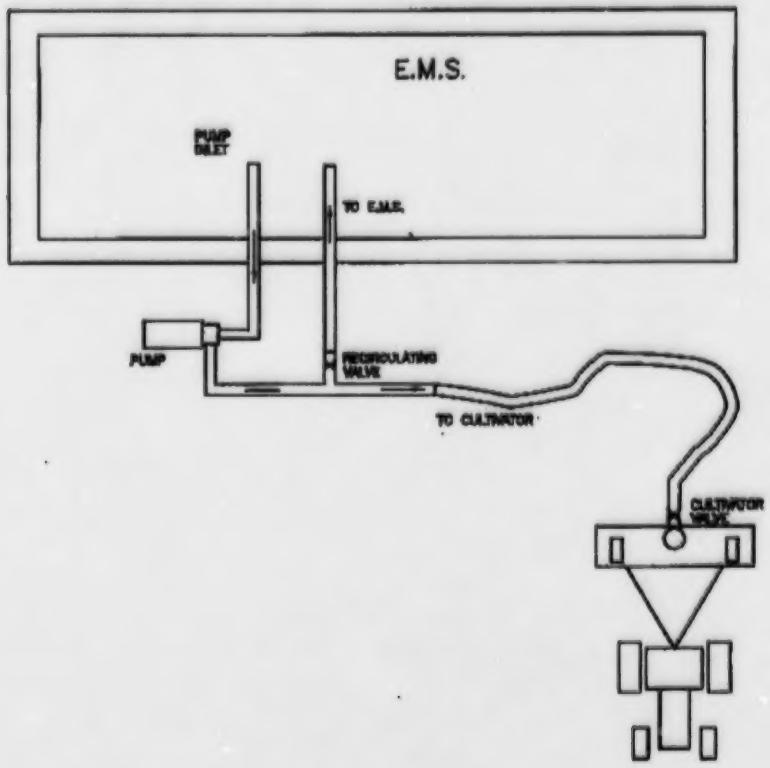

Figure 2. EMS Schematic.

All components were purchased with standard flanges and then bolted together as a unit and attached to the manure pipeline with quick couplers. This allowed for easy removal for servicing or other testing without disrupting manure pumping operations.

Figure 3. EMS Component Assembly.

An aluminum irrigation pipe was used for manure plumbing. The outlet of the recirculating valve was connected to a section of flexible hose that directed the recirculated manure back in to the EMS. Because no hydraulics were available as a part of the main manure pump, a separate hydraulic pump with associated pressure and flow control valves was used to control the positioning of the recirculating valve. Electrical power (12 V DC) for all EMS control system components was taken from the main manure pump engine.

The portion of the control system that was at the EMS was housed in a weatherproof cabinet. This unit included controls for system power, and local and remote control. Lights were used to indicate valve positions, operation status, and error conditions. An antenna was mounted on a stake about 20 ft. high and a cable connected the antenna to the control unit.

The tractor electronics were mounted in a separate box in the tractor cab. Switches controlled the system power and local control of the cultivator valve. An antenna was mounted on the top of the tractor cab.

The control system operated in the following manner. When the EMS unit is first turned on, the unit goes into "safe" mode (the recirculating valve open) and waits for a RF (radio frequency) signal from the tractor unit. When the tractor unit is turned on, it attempts to communicate with the EMS unit. When this communication is established, the control system positions the recirculating valve to start or stop the manure flow,

depending on the cultivator valve position. When the tractor operator moves the switch in the tractor cab to turn the manure flow off, the control system opens the recirculating valve, and when it is completely open, the cultivator valve is completely closed. When the tractor operator moves the switch in the tractor cab to turn the manure flow on, the control system opens the cultivator valve and when it is opened completely, the recirculating valve is closed completely.

The control system also incorporates a "local" mode, so that both valves could be locally manually controlled from the appropriate control box.

During all opening and closing operations, the control system monitors the valve position, and if the valve movement stopped before the valve was completely opened or closed, an error condition was set, and the control system went into "safe" mode. The error then had to be corrected and both EMS and tractor units reset before manure flow could be continued. The same was true if the RF signal was lost for too long of a time period.

Both the EMS and tractor units are continually communicating with each other to monitor switch and valve positions and confirm that the RF link is established. Any reprogramming of the control software or valve position limit settings was originally done using a laptop computer. This required computer programming knowledge, and was therefore not practical except for trained personnel. This was later changed to a system where a potentiometer in the control box was adjusted to change valve position limit settings.

6.4 Field Testing

When the complete system was assembled, some preliminary tests were done with no manure flow. The electronics in the tractor were tested independently by using a laptop computer to simulate the other half of the system. When this part was working correctly, the electronics at the EMS were also independently tested. When both halves of the system seemed to be working correctly, trials were done with the entire system without manure flow. This test revealed some problems in the programming logic, and changes to the programming were made. After the changes were complete, and the system appeared to be working without manure flow, the main manure pump was turned on and the first full scale trials began.

The first full scale trials were carried out with the hydraulic flow control on the recirculating valve set for a 20 second actuation time. At this setting, there was no water hammer in the manure pipeline, and the manure flow appeared to start and stop normally. Manure line pressure during operation was about 135 psi, and this dropped to about 45 psi when the flow to the cultivator was shut off. This pressure was sufficient to keep the flexible part of the drag hose from collapsing or twisting as the cultivator went through a 180° turn. Because all was working well, the actuation time was gradually shortened until an actuation time of 7 seconds was achieved. This was considered acceptable by the operators, as it was fast enough to not significantly affect pump out time without introducing water hammer into the manure pipeline.

During field testing, the electronic control system occasionally did not function correctly. When any type of error condition existed, such as a loss of radio contact or a valve not opening completely, the unit would go into "safe" mode, and the manure flow to the cultivator would be shut off and diverted back to the EMS. Although this prevented any damage to the manure pipeline, it disrupted manure pumping. Initial problems were diagnosed as software programming bugs, and after being corrected, the system operated more reliably.

Another problem that emerged was that it was very difficult to completely seal the linear actuator and other components on the cultivator from manure. Some manure was leaking out from the manure piping joints on the cultivator, and this dripped on to the valve actuator. Even though the actuator was rated for use in wet environments, it was almost impossible to completely ensure that no manure would enter it. When manure did enter the actuator, it resulted in incorrect valve position readings and subsequent incorrect operation. The actuator manufacturer indicated that enclosing the actuator rod in a rubber bellows would help to keep any liquid out of the actuator. This was done along with sealing the motor end of the actuator with a rubber sealing compound.

Manure migrating into unwanted areas created a problem with the valve. After a few hours of operation, the valve would not open fully. This was possibly due to manure solids leaking past the rod seal and into an enclosed chamber that was part of the valve rod support. The valve would then not open completely and the control system would recognize this as an error condition, even though manure flow was not affected much by the valve being partially closed. One option to remedy this situation could have been to dismantle the valve and clean it. This was thought to be impractical in the interest of keeping the manure pump in operation continuing. The remedy that was chosen was to reprogram the control system to recognize the valve as open fully at a different position. This was fairly simple to do, but it originally required knowledge of the control system software and a laptop computer. The incorporation of the potentiometer described at the end of Section 6.3 made this adjustment simpler.

After field testing was complete, some tests were done with the system off the cultivator to determine radio operating range. The valve and control system were set up at PAMI in Humboldt, and the tractor control box was set up in a half ton truck. The stationery antenna was mounted on a 10 ft. high mast, and the truck was driven down the road while attempting to control the valve. The valve could be operated reliably from as far away as 5 miles. This was an adequate distance, as most operators do not pump farther than 2 miles.

Refinements to the control system software were carried out to make the system more reliable and easy to use. The previously mentioned improvements to setting the valve position limits were also incorporated into the software at this time, as well as provisions to monitor manure pressure. A safety system to shut the engine off if the manure pressure was too high was also added.

7. Deviations from Project Plan

The scope of the project has not changed.

10. Equipment

Equipment purchased for this project included all electronic components, a plug valve and actuator, an electric linear actuator, a hydraulic power unit, and a check valve. This equipment is now in the possession of Big Sky Farms.

11. Project Photos

Figure 4. Pipeline Pump Unit.

Figure 5. Injection of Manure with Remote Control.

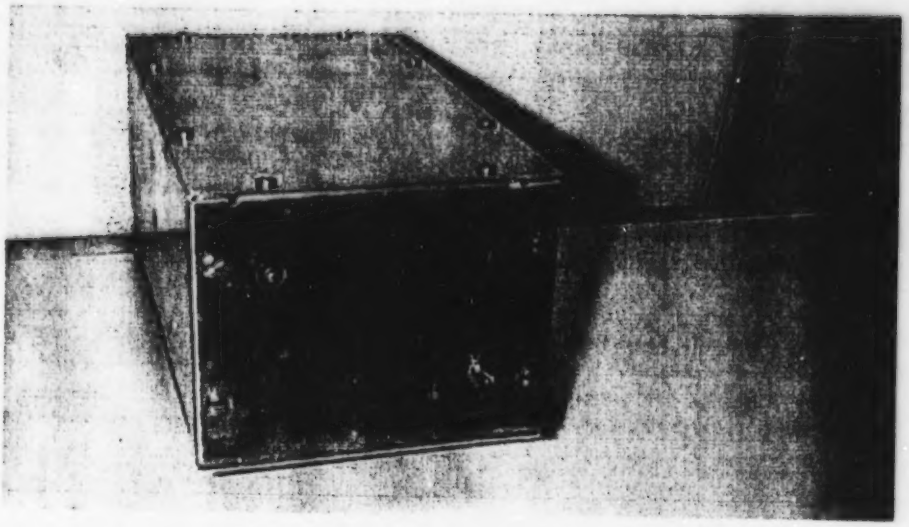

Figure 6. Tractor Control Unit.

Figure 7. EMS Control Unit.

12. Acknowledgements

ADF funding will be acknowledged in all reports and at public demonstrations. This equipment was displayed during the Manure Management '99 tour in June 1999, at which time ADF funding was acknowledged.

AgriSpace Technologies developed the electronics for this project and plans to offer this system for sale to any potential users.